

A

- action at a distance** the force between two objects not in contact (7.2)
- air resistance** friction due to the motion of an object through air; proportional to the object's velocity (1.3)
- alpha particle** one or more helium nuclei ejected from a radioactive nucleus (13.2)
- antimatter** matter composed of antiparticles, which have the same mass but opposite charge, and/or other properties, compared to particles (13.2)
- antineutrino** a chargeless, very low-mass particle involved in weak interactions (13.2)
- apparent weight** the weight measured by a scale; same as true weight, unless the object is accelerating (1.3)
- atomic mass number** the number (A) that represents the total number of protons and neutrons in an atomic nucleus (13.1)
- atomic mass unit** the value of mass equal to mass of the most common carbon isotope ($^{12}_6\text{C}$) divided by 12; $1\text{ u} = 1.6605 \times 10^{-27}\text{ kg}$ (13.1)
- atomic number** the number (Z) that represents the number of protons in the nucleus; also represents the charge of the nucleus in units of e (13.1)

B

- Balmer series** spectral lines of hydrogen that lie in the visible wavelength range (12.3)
- baryon** a subset of the hadron family, such as the proton and neutron, that are composed of combinations of three quarks (13.3)
- beta particle** high-speed electrons or positrons ejected from a radioactive nucleus (13.2)
- betatron** a cyclotron modified to accelerate electrons through magnetic induction, instead of using electric fields (8.3)
- binding energy** 1. the amount of additional energy an object needs to escape from a planet or star (6.1) 2. the amount of energy that must be supplied to nuclear particles in order to separate them (13.1)
- blackbody** an object that absorbs and emits all radiation of all possible frequencies (12.1)

Bohr radius the distance from the nucleus of the lowest allowed energy level in the hydrogen atom: $r = 0.0529177\text{ nm}$ (12.3)

C

- centripetal acceleration** the centre-directed acceleration of a body moving continuously along a circular path; the quotient of the square of the object's velocity and the radius of the circle (2.2)
- centripetal force** the centre-directed force required for an object to move in a circular path (2.2)
- charge density** the charge per unit area (8.1)
- chemical symbol** a shorthand symbol for an element (13.1)
- circular orbit** an orbit produced by a centripetal force (6.2)
- classical physics** the long-established parts of physics, including Newtonian mechanics, electricity and magnetism, and thermodynamics, studied before the twentieth century (12.1)
- closed system** a system that can exchange energy with its surroundings, but not with matter (4.2)
- coefficient of kinetic friction** for two specific materials in contact, the ratio of the frictional force to the normal force between the surfaces when they are in relative motion (1.2)
- coefficient of static friction** for two specific materials in contact, the ratio of the frictional force to the normal force between the surfaces when they are not moving relative to each other (1.2)
- coherent** light that is in phase (the maxima and minima occur at the same time and place) (9.2)
- combustion chamber** the part of an engine where gases are burned (e.g., a jet engine) (6.3)
- Compton effect** a phenomenon involving the scattering of an X-ray photon with a “free” electron, in which, through conservation of energy and momentum, some of the photon's energy is transferred to the electron (12.2)
- conservation of mechanical energy** the change in the total mechanical energy (kinetic plus potential) of an isolated system is zero (5.1)
- conservation of momentum** the total momentum of two objects before a collision is the same as the total momentum of the same two objects after they collide (4.2)

conservative force a force that does work on an object in such a way that the amount of work done is independent of the path taken (5.3)

constructive interference a situation in which a combined or resultant wave has a larger amplitude than either of its component waves (9.1)

coordinate system consists of perpendicular axes that define an origin or zero position and dimensions (1.1)

Coulomb's constant the proportionality constant in Coulomb's law: $k = 9 \times 10^9 \text{ N} \cdot \text{m}^2/\text{C}^2$ (7.1)

Coulomb's law the force between charges at rest, proportional to the magnitudes of the charges and inversely proportional to the square of the distance between their centres (7.1)

counterweight a heavy, movable mass that balances another mass (1.3)

cyclotron a particle accelerator that subjects particles in a circular path to a large number of small increases in potential in order to accelerate them (8.3)

D

daughter nucleus the nucleus remaining after a transmutation reaction (13.2)

de Broglie wavelength the wavelength associated with a particle; the quotient of Planck's constant and the momentum of the particle (12.2)

destructive interference a situation in which a combined or resultant wave has a smaller amplitude than at least one of its component waves (9.1)

deuterium an isotope of hydrogen, consisting of a proton and neutron in the nucleus (13.1)

diffraction the bending of waves around a barrier (9.1)

diffraction grating a device for producing spectra by diffraction and for the measurement of wavelength (9.3)

dilated time the time measured by an observer who sees a clock that is in a frame of reference that is moving relative to the observer (11.2)

dispersion the separation of light into its range of colours (9.1)

doubly refractive having a different refractive index, depending on the polarization of the light (10.1)

dynamics the study of the motions of bodies while considering their masses and the responsible forces; simply, the study of *why* objects move the way they do (1.2)

E

elastic collision a collision in which both momentum and kinetic energy are conserved (4.3)

elastic potential energy a form of energy that accumulates when an elastic object is bent, stretched, or compressed (5.2)

electric field intensity the quotient of the electric force on a unit charge located at that point (7.2)

electric field a region in space that influences electric charges in that region (7.2)

electric field lines imaginary directed lines that indicate the direction a tiny point charge with zero mass would follow if free to move in the electric field; these lines radiate away from positive charges and toward negative charges (7.2)

electric permittivity a number that characterizes a material's ability to resist the formation of an electric field in it (10.1)

electric potential difference the work done per unit charge between two locations (7.3)

electromagnetic force an infinite range force that operates between all charged particles (13.3)

electromagnetic spectrum the range of frequencies of electromagnetic waves (10.3)

electromagnetic wave a wave consisting of changing electric and magnetic fields (10.1)

electron an elementary particle with negative charge and a mass of $9.11 \times 10^{-31} \text{ kg}$ (13.1)

electron volt the energy gained by one electron as it falls through a potential difference of one volt: $1 \text{ eV} = 1.60 \times 10^{-19} \text{ J}$ (12.1)

electrostatic force the force between charges at rest; see also: Coulomb's law (7.1)

electroweak force the fundamental force from which the electromagnetic and weak nuclear forces are derived (13.3)

elementary charge the basic unit of charge: $e = \pm 1.602 \times 10^{-19} \text{ C}$ (13.1)

elementary particle a stable particle that cannot be subdivided into smaller particles (13.3)

empirical equation an equation based on observed data and not on any theory (12.1)

energy the ability to do work (5.1)

equipotential surface a surface in which all points have the same electric or gravitational potential (7.3)

escape energy the amount of energy required for an object to escape from the gravitational force of a planet or star and not return (6.1)

escape speed the minimum speed at the surface of a planet that will allow an object to leave the planet (6.1)

exhaust velocity the backward velocity of the gas ejected from the combustion chamber of a rocket relative to the combustion chamber (6.3)

external force any force exerted by an object that is not part of the system on an object within the system (4.2)

F

Faraday cage a metal screen that is used to shield a region from an external electric field (8.2)

fictitious force a force that must be invoked to explain motion in a non-inertial frame of reference (1.1)

field a region in space that influences a mass, charge, or magnet placed in the region (7.2)

frame of reference a subset of the physical world defined by an observer in which positions or motions can be discussed or compared (1.1)

Fraunhofer diffraction diffraction produced by plane wavefronts of a parallel beam of light (9.2)

free-body diagram a diagram in which all of the forces acting on an object are shown as acting on a point representing the object (1.2)

free fall a situation in which gravity is the only force acting on an object (1.3)

Fresnel diffraction diffraction produced by curved wavefronts, such as that produced by a point source of light (9.2)

frictional forces forces that oppose motion between two surfaces in contact (1.2)

fringe a bright or dark band produced by interference of light (9.2)

G

gamma (γ) an abbreviation of an expression that is used in equations for length contraction and time dilation: $\gamma = \sqrt{1 - \frac{v^2}{c^2}}$ (11.2)

gamma ray high-frequency radiation emitted from a radioactive nucleus (13.2)

geostationary orbit the orbit of a satellite around Earth's equator, which gives the satellite the appearance of hovering over the same spot on Earth's surface at all times (3.2)

gluons exchange particles responsible for holding quarks together (13.3)

gradient a change in a quantity relative to a change in position, or displacement (8.1)

gravitational assist or gravitational slingshot interaction typically between a spacecraft and a planet in which the planet loses a small amount of energy and the spacecraft gains a large amount of energy (6.3)

gravitational field intensity the quotient of the gravitational force and the magnitude of the test mass at a given point in a field; the product of the universal gravitation constant and mass, divided by the square of the distance of a given location from the centre of the object (7.2)

gravitational field lines imaginary directed lines that indicate the direction a tiny test mass would follow if free to move in the gravitational field; these lines radiate inward toward the mass that generates them (7.2)

gravitational force infinite range force that operates between all massive particles (13.3)

gravitational mass the property of matter that determines the strength of the gravitational force; compare to: inertial mass (1.1)

gravitational potential the gravitational potential energy per unit mass (7.3)

graviton exchange particle postulated to be responsible for the gravitational force (13.3)

ground state the lowest possible state that an electron can occupy in an atom (13.3)

H

hadron particles that contain quarks (13.3)

half-life the time in which the amount of a radioactive nuclide decays to half its original amount (13.2)

heat the transfer of thermal energy from one system to another due to their different temperatures (5.3)

heavy water water composed of molecules of oxygen and deuterium instead of oxygen and hydrogen (13.2)

Hooke's law states that the applied force is directly proportional to the amount of extension or compression of a spring (5.2)

Huygens' principle each point on a wavefront can be considered to be a source of a secondary wave, called a "wavelet," that spreads out in front of the wave at the same speed as the wave itself (9.1)

I

impulse the product of the force exerted on an object and the time interval over which the force acts (4.1)

impulse-momentum theorem states that the impulse is equal to the change in momentum of an object involved in an interaction (4.1)

inelastic collision a collision in which momentum is conserved, but kinetic energy is not conserved (4.3)

inertia the natural tendency of an object to stay at rest or in uniform motion in the absence of outside forces; proportional to an object's mass (1.1)

inertial frame of reference a frame of reference in which the law of inertia is valid; it is a non-accelerating frame of reference (1.1)

inertial mass the property of matter that resists a change in motion; compare to: gravitational mass (1.1)

interferometer an instrument for measuring wavelengths of light by allowing light beams to interfere with each other (11.1)

internal force any force exerted on an object in the system due to another object in the system (4.2)

inverse square law the relationship in which the force between two objects is inversely proportional to the square of the distance that separates the centres of the objects; for example, the gravitational and electrostatic forces (7.1)

ion an electrically charged atom or molecule (13.1)

ionizing radiation radiation of sufficient energy to liberate the electrons from the atoms or molecules (13.2)

isolated system a system that does not exchange either matter or energy with its surroundings (4.2)

isotope two or more atoms of an element that have the same number of protons but a different number of neutrons in their nuclei (13.1)

K

Kepler's laws three empirical relationships that describe the motion of planets (3.1)

kinematics the study of the motions of bodies without reference to mass or force; the study of *how* objects move in terms of displacement, velocity, and acceleration (1.2)

L

law of universal gravitation the force of gravity between any two objects is proportional to the product of their masses and inversely proportional to the square of the distance between their centres (3.1)

length contraction a consequence of special relativity, in which an object at rest in one frame of reference will appear to be shorter in the direction parallel to its motion in another frame of reference (11.2)

lepton particles, such as electrons and neutrinos, that do not contain quarks and do not take part in strong nuclear force interactions (13.3)

line spectrum (emission spectrum) a spectrum consisting of bright lines at specific wavelengths, produced by atoms of heated elements (9.3)

linear accelerator a particle accelerator that uses alternating electric fields to accelerate particles in stages (8.3)

Lorentz-Fitzgerald contraction contraction of an object in the direction of its motion (11.1)

M

magnetic field intensity the magnetic force acting on a unit length of a current-carrying wire placed at right angles to the magnetic field, measured in tesla (T) (7.2)

magnetic field lines imaginary directed lines that indicate the direction in which the N-pole of a compass would point when placed at that location; these lines radiate out of the magnet's N-pole and into its S-pole and form closed loops in the magnet (7.2)

magnetic permeability a number that characterizes a material's ability to become magnetized (10.1)

magnetic quantum number determines the orientation of the electron orbitals when the atom is placed in an external magnetic field (13.3)

magnetic resonance imaging a medical imaging technique for obtaining pictures of internal parts of the body in a non-invasive manner (10.2)

mass defect the difference between the mass of a nucleus and the sum of the masses of its

constituent particles; the mass equivalent of the *binding energy* of a nucleus (13.1)

mass spectrometer an instrument that can separate streams of particles by mass and measure that mass by application of electric and magnetic deflecting fields (8.3)

mass-to-charge ratio the quotient of a particle's mass to its charge, which is easier to measure than either quantity individually (13.3)

Maxwell's equations a series of four related equations that summarize the behaviour of electric and magnetic fields and their interactions (10.1)

meson a particle composed of a quark and an antiquark (13.3)

microgravity the condition of apparent weightlessness (3.2)

modulation a process of adding data to an electromagnetic wave by changing the amplitude or frequency (10.2)

momentum the product of an object's mass and velocity (4.1)

N

neutrino a chargeless, very low-mass particle involved in weak interactions (13.2)

neutron a particle with zero charge, found in the nucleus of all atoms except the hydrogen atom (13.1)

nodal point a stationary point in a medium produced by destructive interference of two waves travelling in opposite directions (9.1)

non-conservative force a force that does work on an object in such a way that the amount of work done is dependent on the path taken (5.3)

non-elastic or plastic the description of a material that does not return precisely to its original form after the applied force is removed (5.2)

non-inertial frame of reference an accelerating frame of reference (1.1)

nuclear fission the splitting of a large nucleus into two or more lighter nuclei; usually caused by the impact of a neutron and accompanied by the release of energy (13.2)

nuclear fusion the formation of a larger nucleus from two or more lighter nuclei, accompanied by the release of energy (13.2)

nuclear model a model for the atom in which all of the positive charge and most of the mass are

concentrated in the centre of the atom, while negatively charged electrons circulate well beyond this "nucleus" (12.3)

nucleon the collective term for a particle (proton and/or neutron) in the atomic nucleus (13.1)

nucleon number the total number of nucleons (protons and neutrons) in the nucleus; also called the "atomic mass number" (13.1)

nuclide the nucleus of a particular atom, as characterized by its atomic number and atomic mass number (13.1)

O

open system a system that can exchange both matter and energy with its surroundings (4.2)

orbital quantum number specifies the shape of an electron's orbital or energy level; has integer values of one less than the principal quantum number (12.3)

P

parabola a geometric figure formed by slicing a cone with a plane that is parallel to the axis of the cone (2.1)

parent nucleus the initial nucleus involved in a transmutation reaction (13.2)

particle accelerator an instrument capable of emitting beams of high-speed, subatomic-sized particles, such as protons and electrons (8.3)

Pauli exclusion principle states that no two electrons in the same atom can occupy the same state; alternatively, no two electrons in the same atom can have the same four quantum numbers (13.3)

periodic motion the motion of an object in a repeated pattern over regular time intervals (5.2)

perturbation deviation of a body in orbit from its regular path, caused by the presence of one or more other bodies (3.2)

photoelastic materials that exhibit doubly refractive properties while under mechanical stress (10.1)

photoelectric effect the emission of electrons from matter by radiation of certain frequencies (12.1)

photon a quantum of light or electromagnetic radiation (12.1)

pion a type of meson (13.3)

plane polarized light or an electromagnetic wave in which the vibrations of the electric field lie in

one plane and are perpendicular to the direction of travel (10.1)

polarization the orientation of the oscillations in a transverse wave (10.1)

positron a particle with the same mass as the electron, but with a positive charge; an antielectron (13.2)

potential gradient the quotient of the electric potential difference between two points and the component of the displacement between the points that is parallel to the field (8.1)

principal quantum number describes the orbital or energy level of an electron in an atom (12.3)

projectile an object that is given an initial thrust and allowed to move through space under the force of gravity only (2.1)

proper length the length of an object measured by an observer at rest relative to the object (11.2)

proper time the duration of an event measured by an observer at rest relative to the event (11.2)

proton a positively charged particle found in the nucleus of all atoms (13.1)

Q

quantized a property of a system that occurs only in multiples of a minimum amount (12.1)

quantum a discrete amount of energy, given by the product of Planck's constant (h) and the frequency of the radiation (f): hf (12.1)

quark the family of six types of particles with charges of $\frac{1}{3}$ or $\frac{2}{3}$ of the elementary charge, which comprise all hadrons (13.3)

R

radioactive isotope (radioisotope) an isotope of an element that has an unstable nucleus and therefore disintegrates, emitting alpha, beta, or gamma radiation (13.2)

radioactive material material that contains radioactive nuclei (13.2)

radioactivity the spontaneous disintegration of the nuclei of certain elements, accompanied by the emission of alpha, beta, or gamma radiation (13.2)

range the horizontal distance a projectile travels (2.1)

Rayleigh criterion the criterion for resolution of two point sources, which states that the inner dark ring of one diffraction pattern should coincide with the centre of the second bright fringe (9.3)

reaction mass matter ejected backward from a rocket in order to propel it forward (6.3)

recoil the interaction that occurs when two stationary objects push against each other and then move apart (4.2)

relativistic speeds speeds close to the speed of light (11.2)

resolving power the ability of a telescope or microscope to distinguish objects that are close together (9.3)

rest mass the mass of an object measured by an observer at rest relative to the object (11.3)

restoring force the force exerted by a spring on an object; proportional to the amount of extension or compression of the spring (5.2)

Rydberg constant the constant of proportionality that relates the wavelength of a spectral line in the hydrogen atom and the difference of energy level numbers that produce it:
 $R = 1.09737315 \times 10^7 \text{m}^{-1}$ (12.3)

S

Schrödinger wave equation the basic quantum mechanical equation used to determine the properties of a particle (13.3)

simultaneity a concept that describes events that occur at the same time and in the same inertial reference frame (11.2)

spin quantum number specifies the orientation, up or down, of the electron's "spin"; has values $+\frac{1}{2}$ or $-\frac{1}{2}$ when placed in a magnetic field (13.3)

spring constant the amount of force a spring can exert per unit distance of extension or compression (5.2)

standard model a comprehensive model that describes subatomic particles, their properties, and the force particles that govern their interactions (13.3)

Stoke's law states that the drag force on a sphere moving through a liquid is proportional to the radius of the sphere and its velocity (8.1)

stopping potential in the photoelectric effect, the potential difference required to stop the emission of photoelectrons from the surface of a metal (12.1)

strong nuclear force the fundamental force that holds the parts of the nucleus together (13.1)

superposition of waves when two or more waves propagate through the same location in a medium, the resultant displacement of the

medium will be the algebraic sum of the displacements caused by each wave (9.1)

synchrocyclotron a modified cyclotron, in which the frequency of the accelerating electric field is adjusted to allow for the relativistic mass increase of the particles (8.3)

synchrotron a cyclic particle accelerator that uses a series of magnets around the circular path and several high-frequency accelerating cavities (8.3)

system of particles an arbitrarily assigned group of objects (4.2)

T

tension the magnitude of the force exerted on and by a cable, rope, or string (1.3)

terminal velocity the velocity of a falling object at which the force of friction is equal in magnitude to the force of gravity (1.3)

test charge a charge of a magnitude that is small enough that it will not affect the field being measured; it is used to determine the strength of an electric field (7.2)

threshold frequency the lowest frequency of light (smallest photon energy) that can eject a photoelectron from a particular metal (12.1)

thrust the force with which gases ejected from a rocket push back on the rocket (6.3)

time dilation a consequence of special relativity in which two observers moving at constant velocity relative to each other will each observe the other's clock to have slowed down (11.2)

torsion balance a sensitive instrument for measuring the twisting forces in metal wires, consisting of an arm suspended from a fibre (7.1)

total energy the sum of the rest mass energy of a particle and its kinetic energy (11.3)

total orbital energy the sum of the mechanical (gravitational potential and kinetic) energies of an orbiting body (6.2)

trajectory the path described by an object moving due to a force or forces (2.1)

transmutation the conversion of one element into another, usually as a result of radioactive decay (13.2)

triangulation a geometrical method for determining distances through the measurement of one side and two angles of a right triangle (10.4)

tritium an isotope of hydrogen, consisting of a proton and two neutrons in the nucleus (13.1)

Tychonic system a planetary model in which the Sun and Moon revolve around Earth, but the other planets revolve around the Sun (3.1)

U

ultraviolet catastrophe the significant discrepancy at ultraviolet and higher frequencies between the predictions based on classical physics and observations of blackbody radiation (12.1)

uniform circular motion motion with constant speed in a circle (2.2)

uniform motion motion at a constant velocity (1.2)

uniformly accelerated motion motion under constant acceleration (1.2)

W

W^+ , W^- , Z^0 bosons exchange particles responsible for the behaviour of the weak nuclear force (13.3)

wave function a mathematical expression that is a solution of the Schrödinger wave equation; describes the behaviour of a particle (13.3)

wave-particle duality both matter and radiation have wave-like properties and particle-like properties (12.2)

weak nuclear force a short-range interaction between elementary particles that is much weaker than the strong nuclear force and governs the process of beta decay; one of the four fundamental forces (13.3)

work the transfer of mechanical energy from one system to another; equivalent to a force acting through a distance (5.1)

work function in the photoelectric effect, the minimum amount of energy necessary to remove an electron from a metal surface (12.1)

work-kinetic energy theorem the relationship between the work done by a force on an object and the resulting change in kinetic energy: $W = \Delta E_k$ (5.1)

work-energy theorem the relationship between the work done on an object by a force and the resulting change in the object's potential and kinetic energy: $W = \Delta E_k + \Delta E_p$ (5.1)

Z

Zeeman effect the splitting of the spectral lines of an atom when it is placed in a magnetic field (12.3)